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ARTESIAN WELLS UPON THE GREAT PLAINS.

A LARGE part of the soil upon the great plains east of the Rocky Mountains is, in composition and character, similar to that of the prairies of the States which border upon the Upper Mississippi; and that it needs only the seasonable application of water to make it quite as fertile as the prairies, has been demonstrated in various places by irrigating it with water taken from the rivers. Those plains are not the barren sandy desert, worthless for all human uses, that some have supposed them to be. Although they are much too arid for the growth of cultivated crops without irrigation, there is almost everywhere a scanty, but, in the aggregate, abundant growth of most nutritious grasses, beside a considerable variety of other herbaceous plants. These grasses are not annuals, that come from the seed with the early spring vegetation and become mature before the drought of summer should destroy them, but they are perennial, retaining their vitality not only through the winter like all perennial plants, but through the severe test of the summer drought also. These are the grasses that, only a few years ago, supported the immense herds of buffalo that roamed over those plains, and that now support herds of domestic cattle which, although large, amount to only a tithe of the numbers that might subsist upon those grasses if water for them to drink were everywhere conveniently available.

The spaces between the rivers of the plains are, as a rule, wholly destitute of water in summer and early autumn, the smaller streams that flow there at other portions of the year being dry then. Some of those spaces are so broad as to make them practically impossible to traverse without an artificial supply of water during that portion of the year. To make these broad lands available for grazing purposes, it has been proposed by different persons to procure the necessary water by boring artesian wells;

and others, more hopeful of procuring abundant water from such a source, have proposed that those lands should be thus irrigated for cultivation.

This question has been to some extent publicly agitated for nearly thirty years. In 1854 Professor Jules Marcou, then geologist to the United States Pacific Railroad Surveys, suggested the practicability of obtaining water by means of artesian wells upon the Llano Estacado of New Mexico. Captain John Pope, of the same surveys, strongly urged, in his report of the following year, that practical tests of the question should be made by boring at various localities. An appropriation from Congress having been secured, the enterprise was undertaken under the direction of Captain Pope, and several borings were made in that region, all of which were failures so far as procuring a flow of water at the surface was concerned. Water was reported to exist there, but it did not rise in the borings, and the whole enterprise was therefore abandoned.

In consequence of the failure of these experiments, comparatively little attention was given to the subject until the successful boring of many artesian wells in California, and the reported similar success in some portions of the Desert of Sahara, again drew public attention to the subject of artesian wells upon the plains east of the Rocky Mountains. In 1880 an appropriation was made by Congress for the purpose of boring experimental wells upon those plains, and the expenditure of the same was placed under the direction of the Commissioner of Agriculture. Under this act, Commissioner Le Duc located one of the wells which it provided for, in the valley of the Arkansas River, near Fort Lyon, Colorado. Many accidents and vexatious delays occurred in the prosecution of this work, and in the autumn of 1881, after reaching a depth of about eight hundred feet, it was abandoned by order of the present Commissioner of Agriculture. The cause of the suspension of this work was the exhaustion of the appropriation, and the report of a commission of geologists that had been appointed to make an examination of the region within which that boring was located, that the location was, in their opinion, an unfavorable one.

Beside these enterprises that have been undertaken by the Government, a number of borings have been made in the plains east of the Rocky Mountains by private persons and companies. Two borings have thus been made at Pueblo, Colorado, from

both of which a good flow of water was obtained at a depth of about twelve hundred feet. One has been made at Denver, Colorado, about eight hundred feet deep; one at Cheyenne, Wyoming, about nine hundred feet deep; and one at Carson Station, on the Kansas Pacific Railroad, said to have been thirteen hundred feet deep; all of which were unsuccessful. Various other borings, from fifty to one hundred feet deep, have been made at different places upon the plains, by parties in search of coal, or for other purposes, all of which failed to produce any considerable flow of water at the surface. It will thus be seen that of all the borings which have hitherto been made upon the great plains, only two have been successful, and both of these are located at Pueblo, Colorado. It is true that, in view of the great extent of the region over which these borings are distributed, and the varying conditions of the strata in different districts, even this large proportion of failures does not prove that similar failures will be the rule elsewhere. This proportion is too great, however, not to excite serious misgiving as to the result of future enterprises of this kind, without at least a change in the methods which have hitherto been pursued. It is claimed, and no doubt correctly, that there were local or special reasons why a portion of those enterprises resulted in failure; but there can be no doubt that certain conditions exist in that region, which are so general in their character as to materially affect the question of success or failure of all enterprises of this kind that may be undertaken there. It is the bearing of these conditions upon the general question which I propose to discuss briefly; but, before doing so, it will be necessary to state what those conditions are.

For the purpose of being explicit in the statements I shall make, they will be confined mainly to the region which I have personally examined as a member of the geological commission that has already been referred to—namely, to that part of Colorado which lies east of the eastern base of the Rocky Mountains, and to adjoining portions of Kansas, Nebraska, and Wyoming. How far these statements will be applicable to contiguous portions of the great plains, the reader will be able to judge. The general subject to be discussed in this connection may, for convenience, be divided under three heads—namely, topographical features, geological structure, and meteorological data.

The general aspect and character of the surface of the great plains is much like that of the prairie region which lies to the

eastward of them, with which, indeed, they are continuous, and would be identical, were it not for the aridity of the climate which prevails there. They are, however, more elevated than any portion of the great prairie region, the general rise from the neighborhood of the Missouri River to the base of the Rocky Mountains being constant, but so gentle as to be imperceptible to the eye. Roughly stated, that portion of the great plains which is especially referred to in the following discussions has an average elevation above the level of the sea of between four thousand and five thousand feet. The principal chain of the Rocky Mountains, composed of a compact mass of crowded peaks and gorges, rises upon its western border almost as abruptly as a wall, except that it is bordered by a narrow fringe of foot-hills; while even the higher peaks, some of which are more than fourteen thousand feet above the level of the sea, do not reach an elevation that in full exposure to the influence of the sun would be above the true line of perennial snow-fall in that latitude. Snow is always present there—that is, numerous small snow-fields, some of which have an elevation as low as nine thousand feet above the sea, remain the whole summer through, in the less exposed places among those mountains. From these numerous small snow-fields, and the comparatively abundant rains that fall upon the mountains in summer time, a multitude of small streams arise. These streams find their way out upon the plains, where they quickly unite to form the Arkansas and South Platte rivers respectively, both of which traverse the plains in an easterly direction. These mountain-born streams are constant in their flow the whole year round, but the tributaries of the two rivers named, which have both their rise and *débouchement* upon the plains, flow only during the cooler months, and are dry, or nearly so, during the summer and early autumn.

The geological structure of this portion of the great plains and of the adjacent mountains is very simple, and it may be readily understood by those who are not geologists. The mountains are almost entirely composed of archæan unstratified rocks, which are mostly of coarse, irregular texture, and similar to the granites in composition. The plains are underlaid by six or seven separate formations of stratified rocks, which lie in successive order upon each other, and extend like broad sheets beneath the whole district, the whole being covered as with a

mantle by the superficial deposits of the plains. These formations range in geological age from the Tertiary to the Triassic inclusive. They have an aggregate thickness near the mountains of about eight thousand feet; but they evidently thin out rapidly to the eastward, so that borings would pierce them at a less depth in the eastern part of the district than in the western. The whole series of these strata is flexed up abruptly against the mountains, and their upturned edges enter largely into the structure of the foot-hills there. The lowermost formation of the series is there seen to rest directly upon the archæan rocks; but, whether beneath the plains other formations intervene between the archæan rocks and the lowest group of the series of stratified rocks just mentioned, is not known. This, however, has little practical bearing upon the question of artesian water-supply, because it is believed that, if water should not be obtained in the Triassic formation, the probabilities for success by deeper boring are not encouraging.

The three uppermost of these formations, or groups of strata, which are known as the Laramie, Fox Hills, and Colorado groups respectively (the two latter being of Cretaceous age, and the former occupying an intermediate position between the Cretaceous and Tertiary,) are such in composition and character that they may be regarded as practically impervious to water. The fourth formation in the descending order is the Dakota Group, of the Cretaceous series. This is composed of coarse, rough sandstone, and being but slightly compacted, it is doubtless as pervious to water as any of the ordinary stratified rocks. The fifth formation, the Jurassic, is of an impervious character; and the sixth, the Triassic, is, in part at least, a pervious one. In view of the facts which are yet to be stated, it may be reasonably presumed that both these pervious formations are really water-bearing. In the Valley of the South Platte River the first of these formations has been removed by erosion, exposing the second. In that of the Arkansas, the first and second have been thus removed, and in a part of that valley the third formation has also been removed, exposing for a few miles the fourth, which has just been spoken of as a pervious one.

If borings were to be made upon the plains between the Arkansas and South Platte rivers in the neighborhood of the mountains, it is estimated that the first of the presumably water-bearing formations that have been mentioned may be reached

at a depth of not less than two thousand feet, and the second at from six hundred to eight hundred feet deeper. In the eastern portion of the district these two formations may probably be reached by boring at a much less depth, respectively, than in the western; because, as before remarked, the formations become thinner in that direction. Near the mountains, there are in this district some isolated Tertiary deposits not referred to in the series just described. These are of limited extent, and rise from one hundred to two hundred feet or more above the general level of the plains. They are nearly level, composed of coarse, pervious material, and are drier, if possible, than the plains around them.

In the Valley of the Missouri River the annual rainfall is quite sufficient for the purposes of agriculture; but the amount diminishes to the westward until the minimum is reached, upon the arid plains. The various ranges which constitute the Rocky Mountain system are surrounded on all sides by arid lands, but the rainfall upon the mountains themselves is much greater than it is upon the plains and broad intervalles around them. The following data illustrate these facts so far as they bear upon the subject in hand. At Omaha, Nebraska, the mean annual rainfall is thirty-six and a quarter inches; at North Platte, Nebraska, eighteen and a half inches; in the whole of Colorado east of the Rocky Mountains, and in the adjacent portion of Southern Wyoming, an average of thirteen inches. Pike's Peak, only eighteen or twenty miles from the plains, has a mean annual rainfall of thirty-one and a half inches. The minimum mean annual rainfall that may be depended on for raising a farm-crop is understood to be about twenty-six inches; and in a region having no greater rainfall than this, disastrous droughts are likely to occur at longer or shorter intervals.

We have seen that the three uppermost of the formations which underlie the plains, having an aggregate thickness of probably not less than two thousand feet, are practically impervious to water. Because of this, and of the excessive dryness of the atmosphere during a large part of the year, which causes the evaporation of the scanty rainfall almost as soon as it is precipitated, none of that water can be expected to accumulate in the strata beneath. Beside rainfall, there is no other primary source of water-supply in all that great, elevated region. Therefore, any supply of water that may exist in the strata beneath the dis-

trict I am here considering must be derived from the rainfall that is precipitated, not upon the district itself, but upon the adjoining mountain district—that is, that supply must come from the water that falls upon the upturned edges of the formations at the foot-hills, and from that which constantly flows across them in the mountain streams that reach the plains. While, as is evident, the greater part of that water will flow off to the rivers, a part of it will soak down through the two pervious formations that have already been mentioned. The dip of all the strata being continuous to the eastward, it is plain that this water will, by gravitation, become widely distributed in the two pervious formations, and be held there by the impervious ones which overlie them respectively. If the latter are pierced by borings from the surface of the plains, the water which has thus been confined there will, as is well known, rise by hydrostatic pressure.

Now, let us consider the views that have been expressed by various persons, both publicly and privately, upon the subject of artesian wells upon the great plains. Some have expressed the opinion that those plains may be everywhere irrigated for cultivation by means of artesian wells; but they are mostly of the class who believe that “water may be obtained anywhere, if you only go deep enough.” If such a result were possible, even in the most favored districts, the absurdity of the idea as applied to the district in question is apparent when it is remembered that the annual mean of the rainfall of this district, together with that of the adjoining mountain district which is drained upon it, is much less than the minimum amount that is necessary to raise a farm crop. Beside this, much the greater part of the annual rainfall referred to runs off by the rivers where, however available it may be for purposes of irrigation, it is not to be considered in connection with artesian wells. It is plain, therefore, that if all the wells that might be successfully bored in this district were in operation, it would not be practicable to irrigate more than a small portion of the land by that means.

But is it practicable to irrigate lands for successful farming by means of artesian wells? Perhaps the best accessible information upon that subject is contained in the report of the State Engineer of California for 1880, from which the following data are taken. Up to that time about one thousand wells had been bored in Los Angeles and San Bernardino counties, and too small

a number seem to have been bored in other parts of the State to receive especial discussion in that report. The deeper wells are five hundred feet, but the average depth is from one hundred and fifty to two hundred feet; average cost, four hundred dollars each; average discharge of water per well, 0.1 cubic foot per second. Experience there shows that it takes a flow of one cubic foot per second to irrigate one hundred acres of land. The average well will therefore irrigate ten acres, and the average cost of such a well will add forty dollars per acre to the original cost of the land. The greatest flow from any of these California wells is that of the Burlingame well near Compton, which amounts to 1.7 cubic feet per second; enough to irrigate one hundred and seventy acres. The water of those wells has been found suitable for agricultural purposes, but all artesian water is not so.

Let us apply the data furnished by the California wells to the subject of similar wells upon the great plains within the district under discussion.

The character of the superficial and Tertiary deposits within this district is such that it does not seem probable that any successful artesian wells may ever be obtained in them. If this judgment is correct, no wells are likely to be obtained in this district of as little depth as the deeper of those California wells that have been referred to. It has been explained that the uppermost of the two presumably water-bearing formations which underlie the district cannot probably be reached between the valleys of the Arkansas and South Platte rivers at a less depth than from twelve hundred to two thousand feet. The cost of a well of the lesser depth in this district need not, even under favorable circumstances, be estimated at less than six thousand dollars. If such a well should yield water at the rate of one cubic foot per second, an average result as favorable as can be reasonably expected, it would irrigate one hundred acres of land; but the cost of such a well would add sixty dollars per acre to the original cost of the land. These facts are certainly very unfavorable to the proposition to irrigate the soil of the plains for cultivation by means of artesian wells; especially when we consider the great risk of failure to get an adequate supply of water, if any at all, the risk of obstruction of the flow, and the probability that a greater depth than one thousand two hundred feet must be bored.

But why not go to the valleys, where the presumably water-

bearing formations are nearer to the surface? First because the valleys are already well supplied with water; and second, because each of the two rivers that cross the district in an easterly direction runs upon an anticlinal axis; that is, the strata dip gently away from the river, both northward and southward, although the surface slopes toward it. This condition of the strata in the valley of the Arkansas is the probable cause of the failure of the boring made by the Government near Fort Lyon. The success at Pueblo, in the same valley, but near the mountains, is plainly due to locally favorable dips of the strata there, which are readily recognizable at the surface. The Arkansas and South Platte, each running upon an anticlinal, there is necessarily a broad synclinal axis or depression of all the strata between the two rivers, which, together with the easterly dip, will cause the gathering of any subterranean water that may exist there by gravitation. This is the reason why borings are recommended to be made there, although they must be deeper to reach those strata which, it is presumed, contain water.

These facts, opposed as they are to the hope of profitable irrigation of farming land upon the plains, do not necessarily prove that wells may not be profitably bored at many places there, to be used for other than irrigating purposes. A well giving no more than one quarter of a cubic foot per second would be sufficient to water large herds of cattle, beside supplying the wants of a small hamlet of people. There are many portions of the plains, bearing an abundant growth of grass, but distant from any constant supply of water, where the value of such a well would be many times greater than that of any well could be for purposes of irrigation alone. That many wells of satisfactory capacity may be obtained upon the plains east of the Rocky Mountains, there appears to be no good reason to doubt. Neither is it improbable that in the vicinity of some of the mountains there may be found districts where wells as numerous, copious and as shallow as those of California may be obtained. But the risk of failure has hitherto proved to be so great that no boring ought to be undertaken upon any portion of the great plains without the known results of a careful geological examination of the region by competent persons.

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